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(54) **GAS FLOW DISTRIBUTION RECEPTACLES, PLASMA GENERATOR SYSTEMS, AND METHODS FOR PERFORMING PLASMA STRIPPING PROCESSES**

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C23C 16/455 (2006.01)
H01L 21/311 (2006.01)

(52) **U.S. Cl.**

CPC ***H01J 37/3244*** (2013.01); ***C23C 16/45519*** (2013.01); ***H01J 37/32449*** (2013.01); ***H01L 21/31138*** (2013.01)

(58) **Field of Classification Search**

CPC H01J 37/3244; H01J 37/32449; H01L 21/31138; C23C 16/45519
USPC 118/715; 156/345.33, 345.34
See application file for complete search history.

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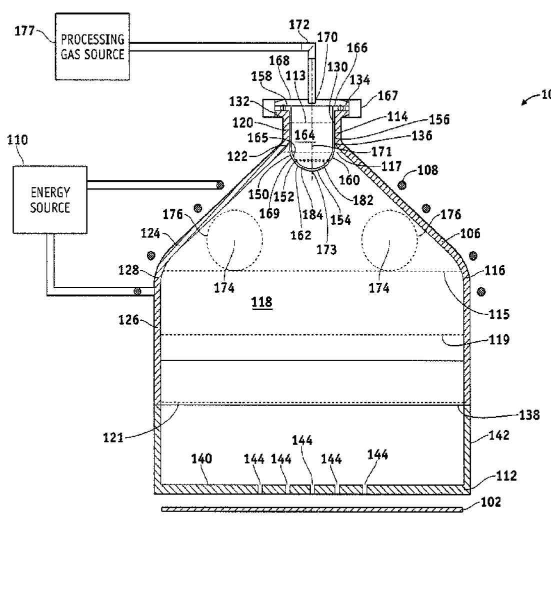
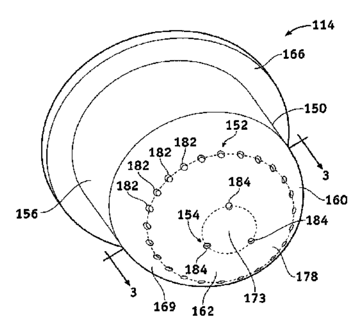
(57) **ABSTRACT**

Systems, system components, and methods for plasma stripping are provided. In an embodiment, a gas flow distribution receptacle may have a rounded section that includes an inner surface defining a reception cavity, an outer surface forming an enclosed end, and a centerpoint on the outer surface having a longitudinal axis extending therethrough and through the reception cavity. First and second rings of openings provide flow communication with the plasma chamber. The second ring of openings are disposed between the first ring and the centerpoint, and each opening of the second ring of openings extends between the inner and outer surfaces at a second angle relative to the longitudinal axis that is less than the first angle and has a diameter that is substantially identical to a diameter of an adjacent opening and smaller than the diameters of an opening of the first ring of openings.

24 Claims, 5 Drawing Sheets





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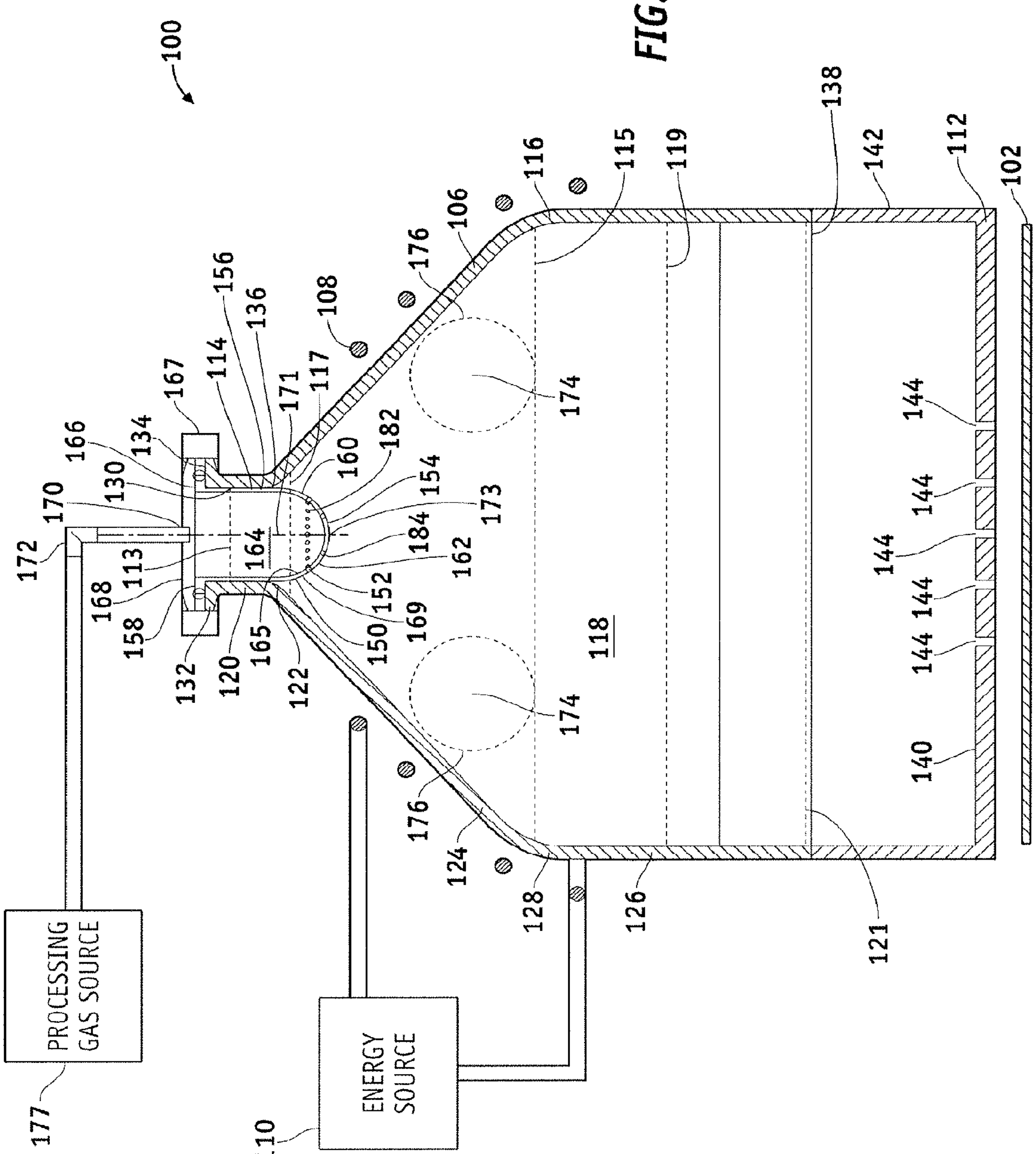

FIG. 1

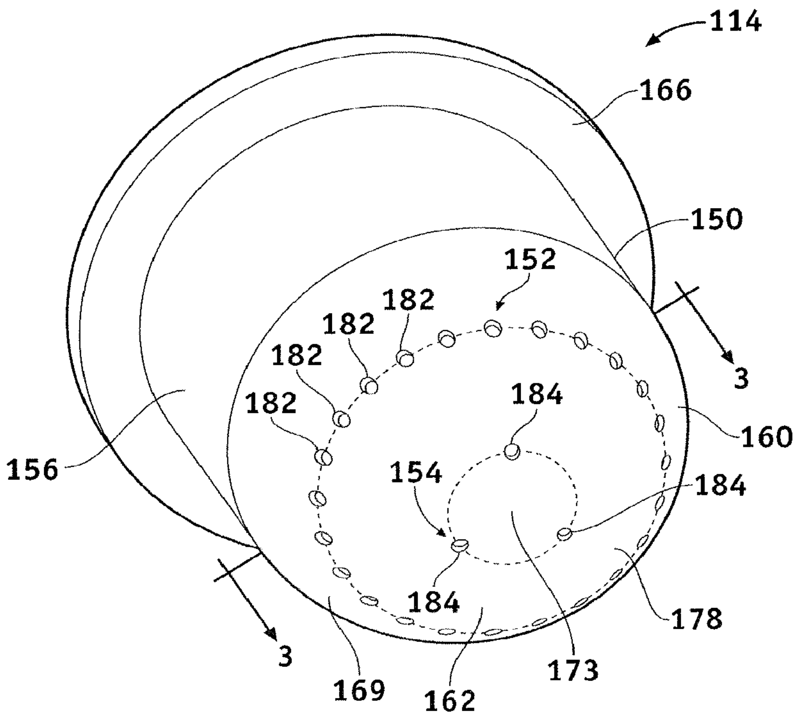
114
166
150
152
182
182
182
182
184
160
156
154
184
184
3
3
178
169
162
173

FIG. 2

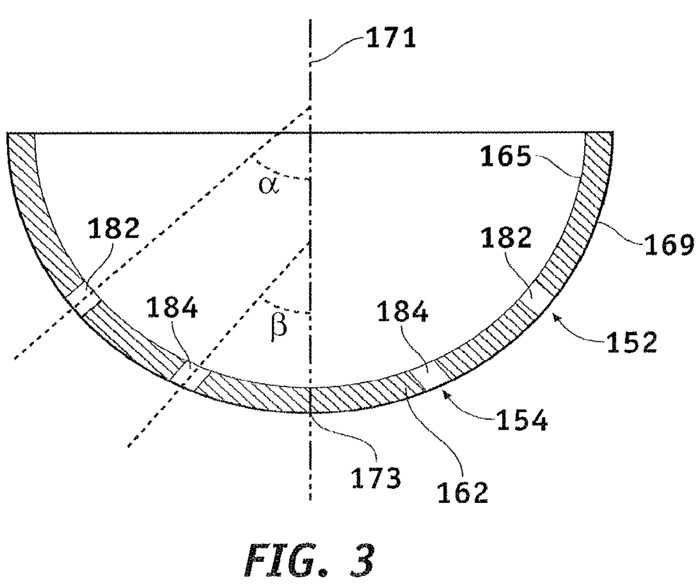
171
α
165
182
169
182
184
β
184
152
154
173
162

FIG. 3

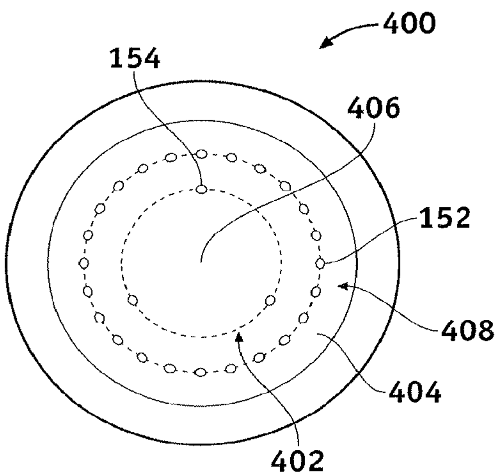

FIG. 4

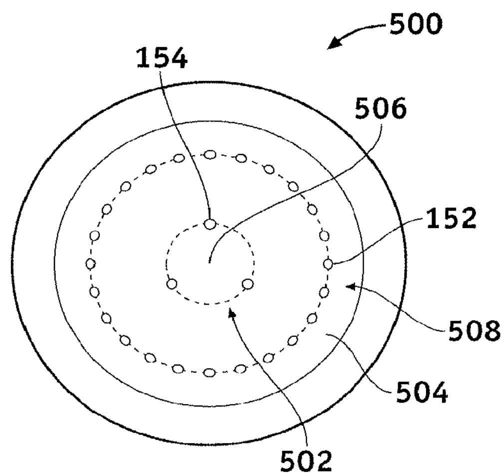

FIG. 5

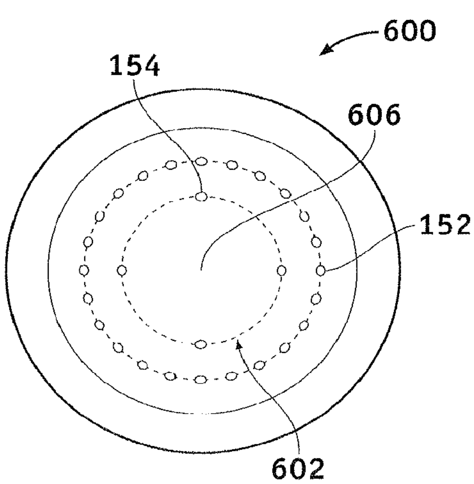

FIG. 6

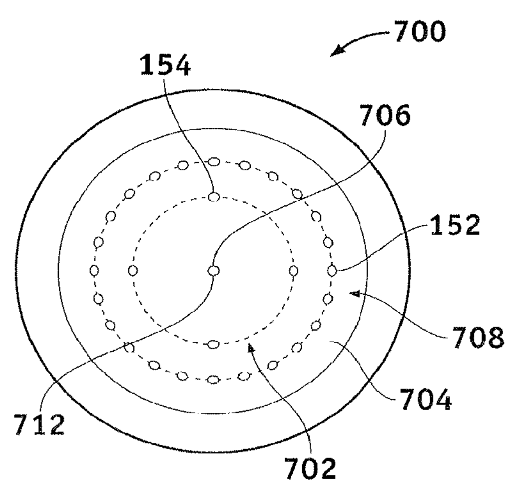

FIG. 7

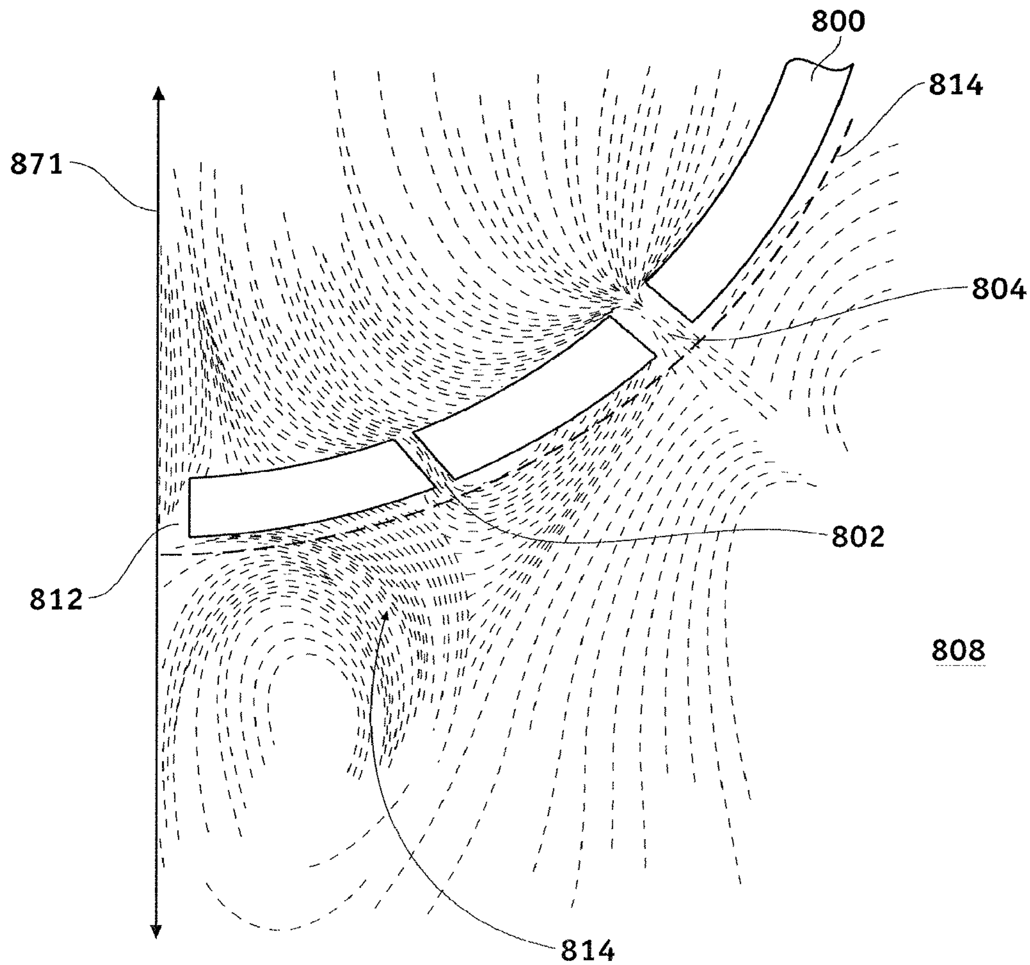

FIG. 8

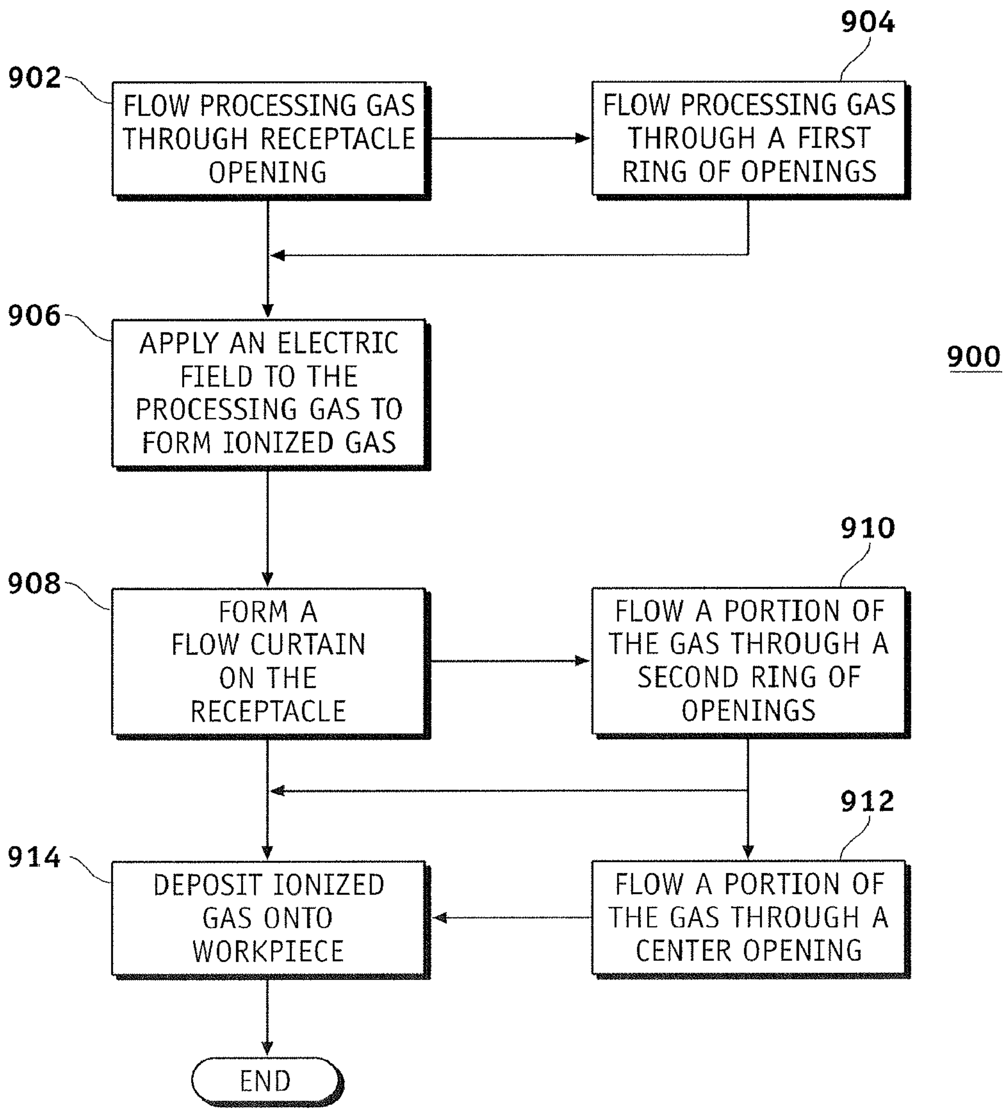
904
902
FLOW PROCESSING GAS THROUGH RECEPTACLE OPENING
FLOW PROCESSING GAS THROUGH A FIRST RING OF OPENINGS
906
APPLY AN ELECTRIC FIELD TO THE PROCESSING GAS TO FORM IONIZED GAS
900
910
908
FORM A FLOW CURTAIN ON THE RECEPTACLE
FLOW A PORTION OF THE GAS THROUGH A SECOND RING OF OPENINGS
912
914
DEPOSIT IONIZED GAS ONTO WORKPIECE
FLOW A PORTION OF THE GAS THROUGH A CENTER OPENING
END

FIG. 9

GAS FLOW DISTRIBUTION RECEPTACLES, PLASMA GENERATOR SYSTEMS, AND METHODS FOR PERFORMING PLASMA STRIPPING PROCESSES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/052,401, filed Mar. 20, 2008 and issued as U.S. Pat. No. 8,110,068 on Feb. 7, 2012, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present invention generally relates to systems, system components, and methods for plasma stripping and more particularly relates to gas flow distribution receptacles, plasma generators, and methods for performing plasma stripping processes using such gas flow distribution receptacles and plasma generators.

BACKGROUND

Plasma stripping, also known as plasma ashing, is a process of removing organic matter and/or residue, such as photoresist, from a workpiece during semiconductor processing. Typically, plasma stripping is performed using a plasma generator. Conventional plasma generators include a tube, a coil, and a processing gas source. The tube may be made of a dielectric material, such as quartz, and may be at least partially surrounded by the coil. An inner surface of the tube defines a plasma chamber that is in flow communication with the processing gas source to receive a processing gas therefrom. To diffuse the processing gas before injection into the plasma chamber, a gas flow distribution receptacle, also made of a dielectric material, may be disposed over an inlet to the plasma chamber. The gas flow distribution receptacle typically includes a ring of evenly spaced openings to provide a flow path between the processing gas source and the plasma chamber.

During operation, the coil is energized and creates an electric field across the plasma chamber. As the processing gas flows through the electric field within the plasma chamber, a portion of the processing gas becomes ionized and forms plasma. The plasma dissociates another portion of the processing gas and transforms it into reactive radicals. The reactive radicals flow to and deposit onto the workpiece, which is disposed adjacent to a dispersion plate or showerhead of the plasma chamber, and react with the organic matter and/or residue thereon to form an easily removable ash or other material.

Although the aforementioned system yields high quality results, the system may be improved. For example, in instances in which the processing gas includes fluorine-comprising gases, such as tetrafluoromethane (CF_4), reactive fluorine radicals may be produced when the fluorine-comprising gas passes through the electric field. In some cases, the reactive fluorine radicals may chemically react with the quartz material of the gas flow distribution receptacle and/or the tube to cause erosion or etching thereof. In other cases, the chemical reaction may produce a silicon oxyfluoride (SiOF) film over the gas flow distribution receptacle and/or the tube. To avoid these unwanted effects, the gas flow distribution receptacle and/or tube are typically replaced once erosion is detected. However, some fluorine-comprising gases may erode or etch the components relatively quickly, and frequent replacement of these components may undesirably increase maintenance costs of the system.

Accordingly, it is desirable to have an improved plasma generator system that may be used in conjunction with fluorine-comprising processing gases such that the gases cause minimal etching of the system components. Additionally, it is desirable for the plasma generator system to include components, such as gas flow distribution receptacles, with improved useful lives compared to components of conventional plasma generator systems to thereby decrease maintenance costs of such systems. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description of the invention and the appended claims, taken in conjunction with the accompanying drawings and this background of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a simplified, cross-sectional view of a plasma generator system, according to an exemplary embodiment of the present invention;

FIG. **2** is a perspective view of a gas flow distribution receptacle that may be used in the plasma generator system depicted in FIG. **1**, according to an exemplary embodiment of the present invention;

FIG. **3** is a close up view of a portion of the gas flow distribution receptacle as indicated by dotted line **3-3** in FIG. **2**, according to an exemplary embodiment of the present invention;

FIG. **4** is an end view of a gas flow distribution receptacle that may be used in the plasma generator system depicted in FIG. **1**, according to another exemplary embodiment of the present invention;

FIG. **5** is an end view of a gas flow distribution receptacle that may be used in the plasma generator system depicted in FIG. **1**, according to another exemplary embodiment of the present invention;

FIG. **6** is an end view of a gas flow distribution receptacle that may be used in the plasma generator system depicted in FIG. **1**, according to another exemplary embodiment of the present invention;

FIG. **7** is an end view of a gas flow distribution receptacle that may be used in the plasma generator system depicted in FIG. **1**, according to another exemplary embodiment of the present invention;

FIG. **8** is a diagram depicting flow of processing gas through a gas flow distribution receptacle, according to an exemplary embodiment of the present invention; and

FIG. **9** is a flow diagram of a method for performing a plasma stripping process, according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION

The following detailed description of the invention is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description of the invention.

FIG. **1** is a simplified, cross-sectional view of a plasma generator system **100**, according to an exemplary embodiment of the present invention. The plasma generator system

100 is configured to selectively remove organic material from a workpiece **102** via plasma stripping. Plasma stripping, also known as "plasma ashing," may be employed to remove organic material, such as, for example, photoresist, organic residues, and/or polymer residues, from the workpiece **102** to clean the workpiece **102**. In addition, plasma stripping also may be used to remove biological contamination from the workpiece **102**, to enhance adhesion of layers to the workpiece **102** prior to deposition of such layers, to reduce metal oxides on the workpiece **102**, or to otherwise etch a range of materials from the workpiece **102**.

The workpiece **102** may be a semiconductor substrate and may be made of relatively pure silicon, germanium, gallium arsenide, or other semiconductor material typically used in the semiconductor industry, or of silicon admixed with one or more additional elements such as germanium, carbon, and the like, in an embodiment. In another embodiment, the workpiece **102** may be a semiconductor substrate having layers that have been deposited thereover during a conventional semiconductor fabrication process. In still another embodiment, the workpiece **102** may be a component, such as a sheet of glass, ceramic, or metal, that may be subjected to plasma stripping to remove unwanted organic materials thereon.

The plasma generator system **100** may be a remote, stand alone apparatus or an in-situ module that is incorporated into a processing system. The plasma generator system **100** shown in FIG. **1** is an example of a remote apparatus. In accordance with an exemplary embodiment of the present invention, the plasma generator system **100** includes a container **106**, a coil **108**, an energy source **110**, a showerhead **112**, and a gas flow distribution receptacle **114**. Although an in-situ module may not be configured identically to the embodiment shown in FIG. **1**, it may include similar components.

The container **106** is configured to receive a processing gas that can be ionized by an electric field and transformed into plasma suitable for dissociating the processing gas into reactive radicals and for removing organic material from the workpiece **102**. In an exemplary embodiment, the container **106** is made of a material that is capable of enhancing the electric field. For example, the container **106** may be made of a dielectric material including, but not limited to quartz, aluminum/sapphire, and ceramic. To contain the plasma therein, the container **106** has a sidewall **116** that defines a plasma chamber **118**. The sidewall **116** has any thickness that is suitable for containing plasma within the container **106** and that does not interfere with the electric field produced by the coil **108**. In an exemplary embodiment, the sidewall **116** has a thickness in a range of from about 4 mm to about 6 mm. In another exemplary embodiment, the sidewall **116** has a substantially uniform thickness (e.g., ±0.5 mm) along its entire axial length. In still another embodiment, the sidewall **116** has a varying thickness along its axial length.

The sidewall **116**, and hence, the plasma chamber **118**, have a shape suitable for allowing the plasma to be directed toward the workpiece **102**. In one exemplary embodiment, the sidewall **116** has a shape that varies along its axial length, as depicted in FIG. **1**. For example, the sidewall **116** may include a neck section **120** extending from an inlet end **122** of a concave section **124** and a tube section **126** extending from an outlet end **128** of the concave section **124**. The neck section **120** may be cylindrical and may have an inlet **130** and a lip **132** that protrudes radially outwardly from an end **134** of the neck section **120** proximate the inlet **130**. In one exemplary embodiment, the neck section **120** has a substantially uniform diameter (shown as dotted line **113**) (e.g., ±0.5 mm) along its axial length. In another exemplary embodiment, the neck section **120** has a varying diameter. In yet another exemplary embodiment, the diameter **113** is in a range of from about 30 mm to about 60 mm.

The concave section **124** may be dome-shaped, cone-shaped, or may have any other shape that is generally concave and that has an outlet end diameter (shown as dotted line **115**) that is greater than an inlet end diameter (shown as dotted line **117**). In one exemplary embodiment, the outlet end diameter **115** is also greater than the diameter **113** of the neck section **120**. In another exemplary embodiment, the outlet end diameter **115** is in a range of from about 150 mm to about 350 mm, while the diameter **113** of the neck section **120** is in the range of from about 30 mm to about 60 mm. In other embodiments, the diameters **115**, **113** may be larger or smaller than the aforementioned ranges. In accordance with another exemplary embodiment of the present invention, the tube section **126** has a substantially uniform diameter (shown as dotted line **119**) that is substantially equal (e.g., ±0.5 mm) to the outlet end diameter **115** of the concave section **124**. In another exemplary embodiment, the diameter **119** of the tube section **126** is greater than the outlet end diameter **115** of the concave section **124**. In yet another exemplary embodiment, the diameter **119** of the tube section **126** is in a range of from about 150 mm to about 350 mm, and the outlet end diameter **115** of the concave section **124** may be in a range of from about 75 mm to about 300 mm. In other embodiments, the diameters **119**, **115** may be larger or smaller than the aforementioned ranges.

The tube section **126** includes an outlet **138** from the plasma chamber **118** that may be at least as large as a diameter of the workpiece **102**. In an exemplary embodiment, the outlet **138** has a diameter (depicted as dotted line **121**) that is in the range of from about 150 mm to about 350 mm. In another exemplary embodiment, the outlet **138** has a diameter **121** that is smaller than or larger than the aforementioned ranges. For example, in embodiments in which only a desired portion of the workpiece **102** is to be subjected to plasma stripping, the diameter **121** of the outlet **138** corresponds to the size of the desired portion.

To allow the processing gas to transform into plasma, the coil **108** surrounds at least a portion of the container **106**. In one exemplary embodiment, the coil **108** is disposed around at least a portion of the concave section **124**. For example, in embodiments in which the concave section **124** is a dome or cone, the coil **108** may be positioned between the inlet end and the outlet end **128** thereof, as illustrated in FIG. **1**. In another exemplary embodiment, the coil **108** additionally, or alternatively, surrounds the tube section **126**. In any case, the coil **108** is made of a conductive material, such as, for example, copper, and is electrically coupled to the energy source **110**. The energy source **110** may be a radio frequency (RF) voltage source or other source of energy capable of energizing the coil **108** to form an electric field. Thus, when the energy source **110** energizes the coil **108**, the electric field is formed in a selected portion of the plasma chamber **118** to thereby ionize the processing gas that may flow therethrough to form ionized gas. As used herein, the term "ionized gas" may include, but is not limited to, ions, electrons, neutrons, reactive radicals, dissociated radicals, and any other species that may be produced when the processing gas ionizes.

A showerhead **112** may be positioned at the plasma chamber outlet **138** to control dispersion of the ionized gas, which may include reactive radicals, across the work piece **102**. In one exemplary embodiment, the showerhead **112** includes a plate **140**. The plate **140** may be made from any suitable material that is relatively inert with respect to the plasma, such as aluminum or ceramic. Generally, the plate **140** is sized to allow gas dispersion over an entirety of the workpiece **102** and thus, has a correspondingly suitable diameter. To allow gas passage therethrough, the plate **140** is relatively porous. In particular, the plate **140** includes through-holes **144** that are suitably sized and spaced to disperse the ionized gas over the work piece **102** in a substantially uniform manner. In one exemplary embodiment, the through-holes **144** have a diameter in a range of from about 2 mm to about 10 mm. In another exemplary embodiment, the through-holes **144** are present at a surface density in a range of from about 0.005 holes/mm^2 to about 0.2 holes/mm. In other embodiments, the through-holes **144** have larger or smaller dimensions than the ranges previously provided. In another exemplary embodiment, the through-holes **144** are substantially uniformly sized (e.g., ±0.5 mm). Additionally, the through-holes **144** are disposed in a substantially uniform pattern on the showerhead **112**, in one exemplary embodiment but, in another exemplary embodiment, the through-holes **144** are disposed in a non-uniform pattern.

In an exemplary embodiment of the present invention, the showerhead **112** is directly coupled to the container **106**, as shown in FIG. **1**. For example, the showerhead **112** may include sidewalls **142** that extending axially from the plate **140** and that are coupled to the container **106** via bolts, clamps, adhesives or other fastening mechanisms. In another exemplary embodiment, the showerhead **112** is not coupled to the container **106** and the plate **140** is positioned at a desired location between the plasma chamber outlet **138** and the workpiece **102**.

The processing gas may be diffused before injection into the plasma chamber **118** to uniformly distribute the gas thereto. In this regard, in one exemplary embodiment, the gas flow distribution receptacle **114** is disposed in a plasma chamber inlet **136**, which may or may not be located at the neck section inlet **130**. For example, as shown in FIG. **1**, the gas flow distribution receptacle **114** is disposed in a portion of the neck section **120** of the container **106**. With additional reference to FIG. **2**, to further enhance even distribution of the processing gas, the gas flow distribution receptacle **114** has a cup member **150** with first and second rings **152**, **154** (rings depicted in phantom) of openings **182**, **184** formed therethrough.

The cup member **150** is made of a material that is non-conductive and is capable of withstanding corrosion when exposed to the processing gas. Suitable materials include, for example, dielectric materials such as quartz. Additionally, in one exemplary embodiment, the cup member **150** has a wall thickness that is substantially identical (e.g., ±0.5 mm) to the thickness of the neck section **120** of the container **106**. In other embodiments, the cup member **150** may be thicker or thinner.

In any case, the cup member **150** may include a cylindrical section **156** and a rounded section **160**. The cylindrical section **156** may define a portion of a reception cavity **164** having an open end **158**. Additionally, the cylindrical section **156** may have an outer diameter that is less than the inner diameter of the plasma chamber inlet **136**. In an exemplary embodiment, a flange **166** extends radially outwardly from the cylindrical section **156**. The flange **166** may be used to retain the gas flow distribution receptacle **114** in position on the container **106** and may be clamped between a cover plate **168** and the container **106**. In this regard, the outer diameter of the flange **166** is at least as large as a diameter of the neck section inlet **130**. In an exemplary embodiment, the outer diameter of the flange **166** is substantially equal (e.g., ±0.5 mm) to the outer diameter of the container lip **132**. In other examples, the outer diameter of the flange **166** may be larger or smaller. In another exemplary embodiment, the cover plate **168** has a diameter that is substantially equal to (e.g., ±0.5 mm) or larger than an outer diameter of the flange **166**. For example, the flange **166** may have an outer diameter that is in the range of from about 40 mm to about 70 mm, and the cover plate **168** may have a diameter that is larger. In other embodiments, the diameters may be smaller or larger. A clamping fixture **167** may surround at least the flange **166**, the cover plate **168**, and the container lip **132** to ensure that the gas flow distribution receptacle **114** remains disposed at a desired location on the container **106**. To allow access into the reception cavity **164**, the cover plate **168** may include one or more openings **170**. The openings **170** may be configured to receive one or more corresponding gas connection lines **172** to provide flow communication with a processing gas source **177**.

The rounded section **160** is generally hemispherically-shaped and has an inner surface **165**, an outer surface **169**, and a centerpoint **173**. The inner surface **165** defines another portion of the reception cavity **164**, and the outer surface **169** forms an enclosed end **162** of the gas flow distribution receptacle **114**. The centerpoint **173** is located on the outer surface **178** of the rounded section **160** and has a longitudinal axis **171** that extends therethrough and through the reception cavity **164**. The first and second rings of openings **152**, **154** are included on the rounded section **160** and are adapted to provide flow communication between the reception cavity **164** and the plasma chamber **118**.

To control the manner in which the processing gas is injected into the plasma chamber **118**, the openings **182** of the first ring **152** are disposed within the rounded section **160** so that the processing gas flows along predetermined gas injection paths. The gas injection paths generally allow the gas to flow axially from a first location in the reception cavity **164** through openings **152** to a second location substantially (e.g., ±0.5 mm) at a center **174** of a plasma zone **176** (indicated by dotted circles). The plasma zone **176** is toroidally-shaped due to the placement of the coils **108** around the container **106** and is identified by an area of the plasma chamber **118** having a highest density of plasma during plasma stripping. In an exemplary embodiment, the first location is a point in the reception cavity **164** that optimizes a pressure difference between the reception cavity **164** and the plasma chamber **118** to thereby maximize a velocity of the processing gas, while minimizing a distance to the plasma zone center **174**. For example, the first location may be a point in the reception cavity **164** that is substantially equidistant (e.g., ±0.5 mm) from each point on a circumference of an inner surface of the rounded section **160**. It will be appreciated that the location of the first ring **152** of openings **182** on the cup member **150** may depend on a particular location of the plasma zone center **174** within chamber **118**.

The number of openings **182** included in the ring **152**, the size of the openings **182**, and the direction in which the openings **182** are formed relative to the receptacle outer surface **169** may be further selected to further control the manner in which the gas is injected. For example, to substantially evenly distribute the processing gas within the plasma chamber **118**, the first ring **152** of openings **182** may include twenty to thirty openings. In one particular example, twenty-four openings may be included, as shown in FIG. **2**. In still other embodiments, more or fewer openings may be included. In one exemplary embodiment, the openings **182** of the first ring **152** are disposed symmetrically about the longitudinal axis **171** and are substantially evenly spaced around a circumference of the rounded section **160**. In another exemplary embodiment, the openings **182** of the first ring **152** are not evenly spaced around a circumference of the rounded section **160**. For example, sets of two or more openings may be formed close together, and each set may be equally spaced from the longitudinal axis **171**. In any case, the openings **182** are spaced such that the processing gas may be substantially evenly injected into the plasma chamber **118**.

In one exemplary embodiment of the present invention, each opening **182** of the first ring **152** has a diameter that is substantially identical (e.g., ±0.5 mm) to a diameter of an adjacent opening **182** in the first ring **152**. In another exemplary embodiment, the openings **182** of the first ring **152** have diameters that vary within a range. For example, each opening **182** may have a diameter that is within a range of from about 0.5 mm to about 3.0 mm. In other examples, the openings **182** may be larger or smaller than the aforementioned diameter range.

Turning to FIG. **3**, a close-up cross-sectional view of a portion of the gas flow distribution receptacle **114** taken along line **3-3** of FIG. **2** is provided. Each opening **182** of the first ring **152** of openings **182** extends between the inner surface **165** and the outer surface **169** of the receptacle **114** at a first angle (α) relative to the longitudinal axis **171**. In an exemplary embodiment, to more evenly disperse the processing gas into the plasma chamber **118**, the first angle (α) is greater than 0° relative to the longitudinal axis **171** and, preferably, is in a range of from about 30° to about 60°. For example, the first angle (α) may be about 45°. In other embodiments, the first angle may be less than or greater than the aforementioned range.

Returning to FIG. **2**, the second ring **154** of openings **184** is configured to form a flow curtain on an outer surface **178** of the rounded section **160** of the gas flow distribution receptacle **114** during system operation. The flow curtain prevents a majority of the ionized gas in the plasma chamber **118**, in particular, the reactive radicals, from depositing onto and contacting the outer surface **178** of the gas flow distribution receptacle **114**. In this regard, the second ring **154** of openings **184** is disposed between the first ring **152** of openings **182** and the centerpoint **173** of the rounded section **160**. FIG. **4** is an end view of a gas flow distribution receptacle **400** that may be used in the plasma generator system **100** depicted in FIG. **1**, according to one exemplary embodiment. Gas flow distribution receptacle **400** is similar to gas flow distribution receptacle **114** except that a second ring **402** of openings **184** is located equidistantly between a first ring **404** of openings **182** and a centerpoint **406** of a rounded section **408** of the gas flow distribution receptacle **400**. FIG. **5** is an end view of a gas flow distribution receptacle **500** that may be used in the plasma generator system **100** depicted in FIG. **1**, according to another embodiment. In this embodiment, gas flow distribution receptacle **500** is similar to gas flow distribution receptacle **400** except that a second ring **502** of openings **184** is located closer to a centerpoint **506** of a rounded section **508** than to the first ring **504** of openings **182**. In one example, the distance from the second ring **502** of openings **184** to the centerpoint **506** may be about 25% of the distance from the first ring **504** of openings **182** to the centerpoint **506**. In other embodiments, the second ring **502** may be closer or further away from the first ring **504**.

It will be appreciated that the number of openings included in the second ring **154** of openings **184** may affect processing gas flow. In one exemplary embodiment, as shown in FIGS. **4** and **5**, three openings are included in the second ring **402**, **502**. In another embodiment, more than three openings are included. FIG. **6** is an end view of a gas flow distribution receptacle **600** that may be used in the plasma generator system **100** depicted in FIG. **1**, according to another embodiment. In this embodiment, gas flow distribution receptacle **600** is similar to gas flow distribution receptacle **114** except that four openings are included in a second ring **602** of openings **184**. In still another exemplary embodiment not depicted, the second ring **602** may include more than four openings. In any case, the openings of the second ring **402**, **502**, **602** may be disposed substantially symmetrically about the longitudinal axis (not depicted in FIG. **4**, **5** or **6**) that extends through the centerpoint **406**, **506**, **606**. In other embodiments, the openings may be disposed asymmetrically, as long as the flow curtain is formed during the plasma stripping process.

Returning back to FIG. **3**, each opening **184** of the second ring **154** of openings **184** may extend between the inner surface **165** and the outer surface **169** of the gas flow distribution receptacle **114** at a second angle (β) relative to the longitudinal axis **171**. In one exemplary embodiment, the second angle (β) is less than the first angle (α) at which the openings **182** of the first ring **152** of openings **182** are disposed, and the second angle is in a range of from about 20° to about 30°. For example, the second angle (β) may be about 22.5°. In other embodiments, the second angle may be less than or greater than the aforementioned range. Each opening **184** of the second ring **154** of openings **184** may have a diameter that is substantially identical (e.g., ±0.5 mm) to a diameter of an adjacent opening **184** in the second ring **154**, but is smaller than the diameter of the openings **182** of the first ring **152** of openings **182**. In one exemplary embodiment, the openings **184** of the second ring **154** of openings **184** are in a range of from about 50% to about 75% smaller than the openings **182** of the first ring **152** of openings **182**. For example, the openings **184** of the second ring **154** of openings **184** may be about 66% smaller. In another exemplary embodiment, the openings **184** may have diameters that range from about 0.5 mm to about 2.5 mm in size. The openings **184** of the second ring **154** of openings **184** may be substantially uniformly sized (e.g., ±0.5 mm) or, alternatively, may vary within a size range.

Turning to FIG. **7**, in an exemplary embodiment, a gas flow distribution receptacle **700**, similar to gas flow distribution receptacle **114**, includes a center opening **712** in addition to the first and second rings **704**, **702**. The center opening **712** is located at a centerpoint **706** of a rounded section **708** of the receptacle **700**. In one exemplary embodiment, the center opening **712** has a diameter that is smaller than the diameters of the openings of the first and the second rings **704**, **702**. For example, the diameter of the center opening **712** may be in a range of from about 0.5 mm to about 1.5 mm. In another embodiment, the diameter of the center opening **712** is substantially equal (e.g., ±0.5 mm) to a diameter of an opening of the second ring **702**.

As briefly mentioned above, by including the second ring **154** of openings **184**, **402**, **502**, **602**, **702** and, optionally, the center opening **712**, on the gas flow distribution receptacle **100**, **400**, **500**, **600**, **700**, a flow curtain forms to prevent a majority of ionized gas circulating in the plasma chamber **118**, and in particular, reactive radicals in the plasma chamber **118**, from depositing or contacting the gas flow distribution receptacle **100**, **400**, **500**, **600**, **700** during a plasma stripping process. FIG. **8** is a diagram depicting flow of a processing gas through a gas flow distribution receptacle **800** that was constructed similar to the gas flow distribution receptacle **700** described above. The gas flow distribution receptacle **800** had a first ring of openings that included twenty-four (24) openings **804**. Each opening **804** of the first ring extended through the receptacle **800** at an angle of about 45° from the longitudinal axis **871** and had a diameter of about 1.5 mm. The center opening **812** had a diameter of about 1 mm. The second ring of openings was disposed substantially equidistantly (e.g.,

±0.5 mm) from the first ring of openings and the center opening **812** and had three (3) openings. Each opening **802** of the second ring of openings extended through the receptacle **800** at an angle of about 22.5° from the longitudinal axis and had a diameter of about 0.8 mm. The processing gas included a mixture of O_2, N_2, and CF_4, and was flowed into the receptacle **800** at a flow rate of about 100 m/s.

As illustrated in FIG. **8**, a first portion of the processing gas flowed through the openings **804** of the first ring of openings into the plasma chamber **808** and then recirculated and carried reactive radicals toward the receptacle **800**. A second portion of the processing gas flowed through the openings **802** of the second ring of openings and through the center opening **812**. This second portion of the processing gas then divided such that some of the gas flowed into the plasma chamber **808** and some remained close to the surface of the gas flow distribution receptacle **800** to create a flow curtain (indicated by dotted line **814**) thereover. The flow curtain **814** pushed the recirculated gas from the plasma chamber **808** away from the receptacle **800** to swirl in the chamber **808**, rather than contact the receptacle **800**.

As noted above, the plasma generator system **100** may be used for plasma stripping processes. FIG. **9** is a flow diagram of a method **900** of performing a plasma stripping process, according to an exemplary embodiment of the present invention. First, processing gas is flowed through openings, such as openings **182** of the first ring **152** of openings **182** shown in FIGS. **1-3**, formed in a gas flow distribution receptacle, step **902**. In an exemplary embodiment, the processing gas comprises one or more gases that may be ionized to form reactive species that can be deposited onto the workpiece to remove unwanted organic material therefrom. The particular gas selected for the processing gas may depend on the particular organic material to be removed. In an exemplary embodiment, the processing gas includes a fluorine-comprising gas. Examples of fluorine-comprising gases suitable for use include nitrogen trifluoride (NF_3), sulfur hexafluoride (SF_6), hexafluoroethane (C_2F_6), tetrafluoromethane (CF_4), trifluoromethane (CHF_3), difluoromethane (CH_2F_2), octofluoropropane (C_3F_8), octofluorocyclobutane (C_4F_8), octofluoro [1-]butane (C_4F_8), octofluoro[2-]butane (C_4F_8), octofluoroisobutylene (C_4F_8), fluorine (F_2), and the like. In another embodiment, the processing gas may additionally comprise an oxygen-comprising gas. For example, the oxygen-comprising gas may include, but is not limited to, oxygen (O_2) and N_2O. In other embodiments, the processing gas may additionally comprise an inert gas, such as, for example, nitrogen (N_2), helium, argon, and the like. In one exemplary embodiment, the processing gas may be a mixture of gases, such as $O_2/N_2/CF_4$ at a ratio of 20:8:1 by flow percent. In other embodiments, the mixture may include different ratios of the aforementioned gases. In still other embodiments, different gases and different ratios may be used.

In an exemplary embodiment, a first portion of the processing gas flows through a first ring of openings of the gas flow distribution receptacle into a plasma chamber in flow communication therewith, step **904**. Each opening of the first ring of openings extends through the gas flow distribution receptacle in a manner substantially similar to the descriptions above with respect to FIGS. **2-7**. In particular, each opening may be formed at a first angle relative to a longitudinal axis that extends through a centerpoint of a rounded section of the receptacle. In an exemplary embodiment, the first angle at which each opening of the first ring of openings is formed is in the range of from about 30° to about 60° relative to the longitudinal axis. Each opening may have a diameter that is substantially identical (e.g., ±0.5 mm) to a diameter of an adjacent opening in the first ring.

An electric field is applied to the processing gas to transform the processing gas into an ionized gas including reactive radicals, step **906**. In an exemplary embodiment, a coil around the plasma chamber is energized to form an electric field. The electric field extends across the plasma chamber to form a plasma zone. As the processing gas flows into the plasma zone, a portion of the gas ionizes to form plasma, and the plasma dissociates another portion of the gas to form reactive radicals. For example, in an embodiment in which the processing gas includes a fluorine-comprising gas, a portion of the fluorine-comprising gas ionizes to form plasma. The remaining portion of the fluorine-comprising gas may be dissociated by the plasma and transformed into reactive fluorine radicals. In an exemplary embodiment of the present invention, some of the reactive fluorine radicals may flow through the plasma chamber, through a showerhead, and may deposit on the workpiece, while another portion of the reactive fluorine radicals may recirculate within the plasma chamber before depositing onto the workpiece.

To prevent a majority of the ionized gas including the reactive radicals in the plasma chamber from depositing onto the outer surface of the gas flow distribution receptacle, a flow curtain is formed thereon, step **908**. In an exemplary embodiment, a second portion of the gas flows into the plasma chamber through a second ring of openings formed in the rounded section between the centerpoint of the rounded section and the first ring of openings, step **910**. Each opening of the second ring of openings is formed substantially identically as described above with respect to FIGS. **2-7**. In particular, each opening of the second ring of openings extends through the gas flow distribution receptacle at a second angle relative to the longitudinal axis that is less than the first angle. In an exemplary embodiment, the second angle at which each opening of the second ring of openings is formed is in a range of from about 20° to 30° relative to the longitudinal axis. In another embodiment, the second angle at which each opening of the second ring of openings is formed is about 22.5° relative to the longitudinal axis. Each opening may have a diameter that is substantially identical (e.g., ±0.5 mm) to a diameter of an adjacent opening in the second ring and that is less than the diameters of each opening of the first ring of openings.

In an optional embodiment, a third portion of the gas flows into the plasma chamber via a center opening formed in the center of the gas flow distribution receptacle on the longitudinal axis to form another portion of the flow curtain, step **912**. The center opening may have a diameter that is less than that of the openings of the first and second rings of openings, in an embodiment. In another embodiment, the center opening has a diameter that is substantially equal (e.g., ±0.5 mm) to that of the openings of the second ring of openings.

As mentioned briefly above, the ionized gas is then deposited onto the workpiece, step **914**. For example, the ionized gas, including reactive radicals, flows from the plasma chamber, through the showerhead, onto the workpiece.

Hence, an improved plasma generator system has been provided that may be used in conjunction with fluorine-comprising processing gases with reduced etching of the system components, as compared with conventional plasma generator systems. Additionally, improved gas flow distribution receptacles having improved useful lives as compared to components of conventional plasma generator systems have been provided. The inclusion of these improved gas flow distribution receptacles may decrease maintenance costs of plasma generator systems.

While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

1. A gas flow distribution receptacle for providing gas flow to a plasma chamber for forming an ionized gas, the gas flow distribution receptacle comprising a rounded section comprising:

an inner surface defining a reception cavity;

an outer surface forming an enclosed end of the rounded section; and

a centerpoint on the outer surface, the centerpoint having a longitudinal axis extending therethrough and through the reception cavity,

a first ring of openings, each opening of the first ring of openings extending between the inner surface and the outer surface and having a first diameter; and

a second ring of openings, the second ring of openings disposed between the first ring of openings and the centerpoint and configured to form a flow curtain over the outer surface of the receptacle to substantially prevent contact between the ionized gas and the outer surface of the receptacle, each opening of the second ring of openings extending between the inner surface and the outer surface and having a second diameter that is smaller than the first diameter.

2. The receptacle of claim **1**, wherein the second diameter is about 50% to about 75% less than the first diameter.

3. The receptacle of claim **1**, wherein the first diameter is between about 0.5 mm and about 3.0 mm.

4. The receptacle of claim **1**, wherein the second diameter is between about 0.5 mm and about 2.5 mm.

5. A gas flow distribution receptacle for providing gas flow to a plasma chamber for forming an ionized gas, the gas flow distribution receptacle comprising a rounded section comprising:

an inner surface defining a reception cavity;

an outer surface forming an enclosed end of the rounded section; and

a centerpoint on the outer surface, the centerpoint having a longitudinal axis extending therethrough and through the reception cavity,

a first ring of openings, each opening of the first ring of openings extending between the inner surface and the outer surface at a first angle relative to the longitudinal axis; and

a second ring of openings, the second ring of openings disposed between the first ring of openings and the centerpoint and configured to form a flow curtain over the outer surface of the receptacle to substantially prevent contact between the ionized gas and the outer surface of the receptacle, each opening of the second ring of openings extending between the inner surface and the outer surface at a second angle relative to the longitudinal axis that is less than the first angle.

6. The receptacle of claim **5**, wherein the first angle is between about 30° and about 60°.

7. The receptacle of claim **5**, wherein the second angle is between about 20° and about 30°.

8. A gas flow distribution receptacle for providing gas to a plasma generation system for forming ionized gas, the receptacle comprising:

an inner surface;

an outer surface;

a centerpoint; and

a rounded section comprising a first ring including a first plurality of openings configured to create a flow curtain that pushes ionized gas away from the outer surface of the receptacle.

9. The receptacle of claim **8**, wherein the first plurality of openings includes at least three openings.

10. The receptacle of claim **8**, wherein openings of the first plurality of openings are symmetrically disposed around a longitudinal axis extending through the centerpoint.

11. The receptacle of claim **8**, wherein the rounded section further comprises a second ring including a second plurality of openings, the first ring between the second ring and the centerpoint.

12. The receptacle of claim **11**, wherein the second ring is substantially equidistant from the first ring and the centerpoint.

13. The receptacle of claim **11**, wherein the second plurality of openings includes twenty to thirty openings.

14. The receptacle of claim **11**, wherein openings of the second plurality of openings are symmetrically disposed around a longitudinal axis extending through the centerpoint.

15. The receptacle of claim **11**, wherein a longitudinal axis extends through the centerpoint, wherein each opening of the first plurality of openings extends between the inner surface and the outer surface at a first angle relative to the longitudinal axis, and wherein each opening of the second plurality of openings extends between the inner surface and the outer surface at a second angle relative to the longitudinal axis.

16. The receptacle of claim **15**, wherein the first angle is greater than the second angle.

17. The receptacle of claim **15**, wherein the first angle is between about 20° and about 30°.

18. The receptacle of claim **15**, wherein the second angle is between about 30° and about 60°.

19. The receptacle of claim **11**, wherein each opening of the first plurality of openings has a first diameter, and wherein each opening of the second plurality of openings has a second diameter.

20. The receptacle of claim **19**, wherein the second diameter is greater than the first diameter.

21. The receptacle of claim **19**, wherein the second diameter is about 50% to about 75% greater than the first diameter.

22. The receptacle of claim **19**, wherein the first diameter is between about 0.5 mm and about 2.5 mm.

23. The receptacle of claim **19**, wherein the second diameter is between about 0.5 mm and about 3.0 mm.

24. The receptacle of claim **8**, further comprising a flange at an end of the receptacle opposite to the centerpoint.

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